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Water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation

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ABSTRACT

The main goal of this research was to measure cotton water use, and to determine irrigation water scheduling parameters associated with optimal seed-lint yield and irrigation water use efficiency, which are poorly understood in the Central Asian Republic of Uzbekistan. A cotton (*Gossypium hirsutum* L.) field experiment with drip irrigation in comparison to furrow (conventional) irrigation was conducted on a deep silt loam soil (Calcic Xerosol) at the Central Experiment Station of the Uzbekistan National Cotton Growing Research Institute at Tashkent in 2003, 2004 and 2005. To investigate irrigation scheduling, the field capacity (F_C) index was adopted, which was 0.30 m^3 m^{-3} in this soil. Irrigations were scheduled when soil water in the root zone was depleted to specific fractions of F_C, e.g., 70% of F_C, for each of three main plant growth periods (germination–squaring; squaring–flowering; beginning of maturation–maturation). Crop water use, which we here define as the sum of transpiration and evaporation, was established using the soil water balance approach on a weekly basis. Soil profile water content was determined using a neutron moisture meter (NMM), which was calibrated in polyvinyl chloride (PVC) access tubes for each differing soil layer. Under drip irrigation and the optimal mode (70–70–60% of F_C) of irrigation scheduling, 18–42% of the irrigation water was saved in comparison with furrow irrigated cotton grown under the same condition; and irrigation water use efficiency increased by 35–103% compared with that of furrow irrigation. Seed-lint cotton yield was increased 10–19% relative to that for furrow irrigated cotton. The irrigation scheduling rule developed here should be considered an improved practice for drip irrigated cotton that is applicable to irrigated Calcic Xerosols of Uzbekistan.

1. Introduction

Agriculture in Uzbekistan was and still is the largest sector in Uzbekistan's economy. Cotton and wheat are the major crops in Uzbekistan followed by maize, vegetables and fruits. About 60% of the country is (semi-) desert with only 4 million ha of irrigated area in the country of 447,000 km^2 surface area. With annual rainfall of 100–300 mm, Uzbekistan's climate is that of the dry mid-latitude desert, with a continental climate that is characterized by hot summers and cold winters. Thus, agricultural production in the country, like in the whole of Central Asia, is predominantly based on irrigation, which

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makes irrigation water supply and management the major factors limiting crop yields in the region.

Water, used for hydro-electric generation and irrigation, is supplied by two major river systems: the Amu Darya and Syr Darya, which also supply the neighboring countries of Kyrgyzstan, Tajikistan, Afghanistan, Turkmenistan and parts of Kazakhstan. Although water supply was formerly centrally arranged, since independence in 1991 these Central Asian countries have continued their dispute on meeting their individual and increasing water demands. Since then, lack of water has gradually devastated the irrigation-dependent cotton, winter wheat and other major crop production. In addition, lack of water has engendered the ecological catastrophe within the Aral Sea Basin, at the tail end of the river systems of Uzbekistan and Kazakhstan.

Approaches to dealing with water scarcity include efforts to improve crop water use efficiency (WUE) by changing irrigation methods (furrow, drip, sprinkler, etc.), applied amounts (deficit irrigation), crops, tillage practices, and other management methods. When the crop cannot be changed due to its economic importance, which is the case with cotton in Uzbekistan, then changes in irrigation methods and management are key to improving WUE. Water use efficiency may be calculated as units of dry yield per unit land area (Y, kg m^{-2}) divided by units of water consumed by the crop per unit land area (ET, $m^3\,m^{-2}$, usually reported as mm) to produce that yield, or:

$$\mathrm{WUE} = \frac{Y}{\mathrm{ET}} \tag{1}$$

where WUE is in kg m^{-3}, and ET is crop evapotranspiration, which can be expressed as a depth of water (m). Another key parameter for evaluating cropping system efficiency is the irrigation water use efficiency (IWUE, kg m^{-3}):

$$\mathrm{IWUE} = \frac{Y - Y_D}{I} \tag{2}$$

where Y is dry yield under the irrigated condition, Y_D the dry yield (kg m^{-2}) under dryland (no-irrigation) conditions, and I is the irrigation water applied (m).

Cotton water use and WUE can be affected by irrigation method and amount. Several studies have found that drip irrigation increased lint yields and WUE by large amounts compared with those from sprinkler or surface irrigation (Smith et al., 1991; Bordovsky, 2001; Janat and Somi, 2002; Kamilov et al., 2003). Colaizzi et al. (2005) found that drip irrigation produced significantly larger yield and WUE than did spray or low energy precision application (LEPA) in 1 of 2 years; but, WUE values, which ranged from 0.152 to 0.194 kg m^{-3}, were not appreciably different for full irrigation and deficit irrigation at 75% of the full amount. Howell et al. (2004) found larger WUE for deficit (half the full amount) sprinkler irrigated cotton in only 1 of 2 years. Values of WUE ranged from 0.144 to 0.219 kg m^{-3} in the latter study, and water use ranged from 578 to 775 mm while lint yield ranged from 0.65 to 1.31 Mg ha^{-1}. Water use in the Colaizzi et al. (2005) study ranged from 410 to 725 mm and lint yield ranged from 0.78 to 1.15 Mg ha^{-1}. Both the Colaizzi et al. (2005) and Howell et al. (2004) studies were in the High Plains of Texas.

Grismer (2002) reported that lint yields averaged 1.33 Mg ha^{-1} for Upland and 1.08 Mg ha^{-1} for Pima in the Central Valley of California for fully irrigated cotton, which is slightly larger than yields from the well-irrigated cotton fields in Texas. The same California study reported that maximum WUE values were in the range of 0.19–0.21 kg m^{-3}, also similar to top end values in the Texas High Plains, which have a much shorter growing season. Ayars et al. (1999) reported data that showed on average a larger WUE (0.30–0.33 kg m^{-3}) for drip irrigated cotton in the Central Valley of California than for furrow irrigated cotton (0.23–0.32 kg m^{-3}), but results may have been biased by different crop coefficients used for the drip irrigation scheduling. In the survey of Grismer (2002), drip system WUE values were typically $>$0.21 kg m^{-3} and sometimes $>$0.30 kg m^{-3}.

Prior to this study, investigation of cotton irrigation scheduling and WUE under irrigation water deficiencies and different irrigation application methods had not been conducted in Uzbekistan. Given the contrary and possibly biased WUE results of studies done in California, Texas and elsewhere, it is important to discover if there are important improvements in WUE related to irrigation method and management under conditions in Uzbekistan. The main objectives of this research were to (i) measure cotton water use, yield and WUE under full and deficit irrigation, (ii) compare these for drip and furrow irrigation methods, and (iii) determine irrigation water scheduling parameters associated with larger yield and irrigation WUE.

2. Materials and methods

The field experiment was conducted at the Central Experiment Station of Uzbekistan's National Cotton Growing Research Institute (41°42′N, 69°49′E, 625 m elevation above mean sea level) in 2003, 2004 and 2005 near Tashkent, the capitol. The soil, a silt loam Calcic Xerosol in the FAO taxomony, is known in the Russian taxonomy still used in Uzbekistan as an old irrigated typical sierozem; and it has a silt loam texture that is uniform with depth (Table 1) (Shamsiev, 2003). The water table is $>$15 m deep, ensuring an automorphic type of soil formation.

As a starting point for investigations of irrigation scheduling, we adopted as an index the field capacity (F_C), which was 0.30 $m^3\,m^{-3}$ in this soil (Shamsiev, 2003). Irrigations were scheduled when soil water content in the root zone was depleted by the crop to specific fractions of F_C (e.g., irrigation at 70% of F_C) for each of the three main plant growth periods defined below. The experiment was carried out in three replicates and comprised two irrigation scheduling treatments with drip irrigation, and one treatment with furrow irrigation (the conventional control) for comparison. The drip irrigation system, comprising one line of surface drip tape in every other inter-row, was installed in the field after completion of early season inter-row cultivation. Each treatment consisted of scheduling irrigation at specific percentages of F_C during each of three plant growth periods as follows:

1. 65–65–60% of F_C (drip irrigation)
2. 70–70–60% of F_C (drip irrigation)
3. 70–70–60% of F_C (furrow irrigation)

Table 1 – Textural analysis of the Calcic Xerosol at the Tashkent Headquarters of the UNCGRI (Shamsiev, 2003), which is a silt loam throughout

Soil layer (cm)	Soil fractions (sizes) (mm)						
	1–0.25	0.25–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001
0–30	1.0	1.1	13.0	39.5	13.8	16.8	14.8
30–50	1.3	1.2	16.0	40.2	12.8	15.1	13.4
50–70	1.1	1.3	18.4	31.0	13.7	17.5	17.0
70–100	1.0	1.0	13.2	35.2	14.0	18.2	17.4
100–140	1.0	1.1	12.8	35.7	12.8	17.7	17.1
140–170	1.6	2.1	20.4	37.1	10.7	14.6	13.5
170–200	1.1	1.3	15.8	34.3	14.2	16.3	16.1

where the first of the three levels of F_C (e.g., **65**–65–60%) was used from germination to the squaring stage of the crop; the second level (e.g., 65–**65**–60%) was used from squaring to the flowering–fruiting stage; and the third level (e.g., 65–65–**60**%) was used during maturation of cotton bolls. Each replicated plot was 240 m^2 (4.8 m $\times$ 50 m). Irrigation water quantity applied through drip irrigation was measured by an in-line propeller-type flow meter. Water quantity for the furrow irrigation treatment was measured using trapezoidal weirs in the supply ditch and at the end of the furrows where tail water was collected. The 16-mm diameter drip tape (Agrodrip) had emitters spaced at 60 cm; emitter discharge rate was 2 L h^{-1} at the operating pressure of 150 kPa. Irrigations were applied within 2 days after a threshold F_C value was recorded.

Cotton (*Gossypium hirsutum* L., cv. Akdarya-6) was planted, fertilized and harvested as shown in Tables 2–4. Plants were thinned to achieve a population density of 9 plants m^{-2}. Total fertilizer applied over the season was 200 kg N ha^{-1}, 140 kg P ha^{-1}, and 100 kg K ha^{-1}. No herbicides were applied—plots were hand weeded. Plots were triply replicated, and treatment locations were randomized within blocks.

Table 2 – Agronomic practices for 2003 drip and furrow irrigated cotton crop

2002	
Fertilizer application[a]	28 November
Moldboard plowing	30 November
2003	
Soil preparation for seeding, NH_4NO_3 incorporated at 50 kg N ha^{-1}	29 April
Cotton planting	29 April
T1 and T2—hand hoeing	14 May
T3—tractor cultivation	14 May
Thinning	21 May
Spray for aphids	3 June
Hand hoeing (all treatments)	
T1 (drip)	16 June, 10 July, 25 July, 6 August
T2 (drip)	16 June, 8 July, 21 July, 4 August
Inter-row tractor cultivation	
T3 (furrow)	16 June, 10 July, 2 August
NH_4NO_3 applied at 75 kg N ha^{-1}	
T1 (drip)[a]	Squaring: 11 June; first flower: 6 July
T2 (drip)[b]	Squaring: 11 June; first flower: 4 July
T3 (furrow)[c]	Squaring: 10 June; first flower: 6 July
Hand cutting of plant growth point	15–21 August
First cotton pick	2 October
Second cotton pick	16 October

[a] 140 kg P ha^{-1} and 100 kg K ha^{-1} broadcast.
[b] Injected as soluble fertilizer into the drip irrigation system.
[c] At squaring, fertilizer is applied at 12 cm depth and 20 cm from the plant row. At first flower, fertilizer is applied at 5 cm depth and in the middle of inter-row (30 cm from row).

Table 3 – Agronomic practices for 2004 drip and furrow irrigated cotton crop

2003	
Fertilizer application[a]	26 November
Moldboard plowing	28 November
2004	
Soil preparation for seeding, NH_4NO_3 incorporated at 50 kg N ha^{-1}	15 April
Cotton planting	16 April
T1 and T2—hand hoeing	12 May
T3—tractor cultivation	12 May
Thinning	12 May
Spray for aphids	28 May
Hand hoeing (all treatments)	
T1 (DRIP)	11–12 June, 29 June, 12–13 July
T2 (Drip)	11–12 June, 29 June, 12–13 July
Inter-row tractor cultivation	
T3 (furrow)	14 June, 28 July, 13 July
NH_4NO_3 applied at 75 kg N ha^{-1}	
T1 (drip)[a]	Squaring: 22–23 June; first flower: 8 July
T2 (drip)[b]	Squaring: 22–23 June; first flower: 6 July
T3 (furrow)[c]	Squaring: 10 June; first flower: 8 July
Hand cutting of plant growth point	2 August
First cotton pick	26 September
Second cotton pick	29 October

[a] 140 kg P ha^{-1} and 100 kg K ha^{-1} broadcast.
[b] Injected as soluble fertilizer into the drip irrigation system.
[c] At squaring, fertilizer is applied at 12 cm depth and 20 cm from the plant row. At first flower, fertilizer is applied at 5 cm depth and in the middle of inter-row (30 cm from row).

Table 4 – Agronomic practices for 2005 drip and furrow irrigated cotton crop

2004	
Fertilizer application[a]	23 November
Moldboard plowing	23 November
2005	
Soil preparation for seeding, NH_4NO_3 incorporated at 50 kg N ha^{-1}	21 April
Cotton planting	22 April
T1 and T2—hand hoeing	10 May
T3—tractor cultivation	10 May
Thinning	20 May
Spray for aphids	23 May, 10 June
Hand hoeing (all treatments)	
T1 (drip)	30 May, 3 June, 12 June, 27 June, 4 July, 25 July
T2 (drip)	30 May, 3 June, 12 June, 27 June, 4 July, 25 July
Inter-row tractor cultivation	
T3 (furrow)	30 May, 25 July, 2 August
NH_4N0_3 applied at 75 kg N ha^{-1}	
T1 (drip)[a]	Squaring: 14 July; first flower: 28 July
T2 (drip)[b]	Squaring: 5 July; first flower: 16 July
T3 (furrow)[c]	Squaring: 23 June; first flower: 20 July
Hand cutting of plant growth point	15 August
First cotton pick	29 September
Second cotton pick	14 October

[a] 140 kg P ha^{-1} and 100 kg K ha^{-1} broadcast.
[b] Injected as soluble fertilizer into the drip irrigation system.
[c] At squaring, fertilizer is applied at 12 cm depth and 20 cm from the plant row. At first flower, fertilizer is applied at 5 cm depth and in the middle of inter-row (30 cm from row).

Cotton water use was measured by the soil water balance method (Eq. (1)). Considering ET as crop water use, P as precipitation, I as irrigation, R as the sum of runoff and runon, F as flux across the lower boundary of the soil profile (control volume), and ΔS as change in soil water stored in the profile, we know that the soil water balance must sum to zero:

$$ET + \Delta S + R - P - I - F = 0 \quad (3)$$

where the sign conventions are as given in Evett (2002), including the conventions that (i) ET is taken as positive when water is lost to the atmosphere through transpiration and/or evaporation and (ii) ΔS is positive when soil water storage increases over the season. Re-arranging this equation gives the crop water use or ET as

$$ET = -\Delta S + P + I - R + F \quad (4)$$

Precipitation data (P) were taken from the Meteorological Station of the Institute, which is located at the Central Experiment Station.

Key to our investigations was the measurement of soil profile water content. For this purpose we used a neutron moisture meter (NMM) (Campbell Pacific Nuclear International,[1] model Hydroprobe-503DR1.5), which was calibrated for each differing soil layer (Table 5) according to Evett et al. (2007). The profile water content, and thus the calculation of irrigation quantities and times for cotton during the growing season, was determined using the NMM. Volumetric water content of the soil profile was determined twice a week and in two replicates during the experiments by NMM to 2 m depth and for each 20 cm soil layer separately. Before each measurement, a standard count (C_S) of the NMM was determined in five replicates. The mean C_S was divided into each neutron count to calculate the count ratios, C_R, referenced in Table 5. A depth control stand (Evett et al., 2003) was used for both calibration and field measurements in order to ensure accuracy and reproducibility of the 10 cm depth measurement.

Table 5 – Calibration equations for neutron moisture meter serial number H390104791 at the UNCGRI Central Research Station near Tashkent (Evett et al., 2007)

Depth (cm)	Equation	r^2	RMSE ($m^3\,m^{-3}$)
10	$\theta = 0.013 + 1.1752C_R$	0.989	0.011
30–70	$\theta = -0.176 + 0.3759C_R$	0.958	0.014
90–170	$\theta = -0.039 + 0.2463C_R$	0.911	0.010

Equations are in terms of volumetric water content (θ, $m^3\,m^{-3}$) and count ratio (C_R). Measurements were at the depths noted and in 20 cm increments between depths. The coefficient of determination (r^2) and root mean squared error of calibration (RMSE) are shown.

Seasonal crop water use was calculated using Eq. (4); and WUE and IWUE were calculated using Eqs. (1) and (2) with dryland cotton yield assumed equal to zero. Precipitation during the cotton season is typically too small for dryland cotton to succeed, so dryland plots were not planted.

All data were checked for normality. Analysis of variance (ANOVA) of the cotton seed yield was performed using the general linear model (GLM) procedure (SAS Institute, 2003). The same was true for the phenological data, which were analyzed with the repeated measures option. The mean effect of the treatment variables soil moisture (as % F_C) and irrigation method (drip, furrow) and their interactions were compared at a $P < 0.05$ level of significance. An LSD post hoc test compared individual treatment means where the ANOVA test indicated significant ($P < 0.10$) treatment effects. All statistical analyses were performed using SAS software.

3. Results and discussion

Irrigations were applied on different dates for the three treatments due to the differences among the treatments in reaching the critical value of F_C for each growth period (Table 6). The number of irrigations also varied by year due to the different amounts of precipitation received during the growing season (130, 75 and 104 mm in 2003, 2004 and 2005,

[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

Table 6 – Irrigation dates and water depths (mm) applied for the three experimental treatments in 2003, 2004, and 2005

Treatment	Irrigation no.	2003		2004		2005	
		Date	Depth (mm)	Date	Depth (mm)	Date	Depth (mm)
1	1	11 June	36	3 May	40	3 May	40
2	1	13 June	36	3 May	40	3 May	40
3	1	15 June	79	3 May	85	3 May	62
1	2	6 July	46	2 June	45	30 May	60
2	2	4 July	42	2 June	45	25 May	55
3	2	4 July	103	7 June	90	25 May	100
1	3	20 July	46	24 June	45	15 June	50
2	3	17 July	44	22 June	40	7 June	48
3	3	30 July	115	21 June	120	23 June	110
1	4	2 August	65	8 July	48	30 June	58
2	4	30 July	60	7 July	45	25 June	60
3	4	22 August	120	8 August	110	20 July	105
1	5	20 August	65	27 July	46	14 July	62
2	5	15 August	65	26 July	45	4 July	54
3	5	10 September	98	4 August	100	9 August	115
1	6	3 September	50	9 August	48	29 July	55
2	6	2 September	40	9 August	48	16 July	50
3	6			27 August	90	29 August	100
1	7			26 August	45	16 August	50
2	7	14 September	40	16 August	45	29 August	45
3	7						
1	8					30 August	55
2	8			3 September	40	10 August	50
3	8						
1	9					7 September	30
2	9					22 August	46
3	9						
1	10						
2	10					5 September	36
3	10						

Treatment	Total for season		
	2003	2004	2005
1	308	317	460
2	327	348	484
3	515	595	592

respectively) and the differences in air temperature and solar radiation. More irrigations were applied in 2004 than in 2003 due to the relatively smaller precipitation in 2004. In 2005, although precipitation was 29 mm larger than in 2004, the air temperature in 5 of the 6 months of the growing season exceeded the 77-year average (Fig. 1). Also, the precipitation fell more in the early season, with relatively less precipitation later in the 2005 season than in 2004. Thus, more irrigations were applied in 2005 than in 2004. The largest precipitation amount (130 mm) during the three growing seasons was so small that dryland cotton yield would have been zero.

Throughout each season, soil water content remained well below the maximum allowed by the soil porosity, which was calculated from measured bulk density (e.g., Fig. 2). Application of the soil water balance equation, using measured irrigation, rainfall and soil water content changes, allowed calculation of seasonal water use. The value of R in Eq. (2) was assumed to be zero for our experimental conditions because runoff from rainfall was nill and the irrigation water balance was measured with weirs. The value of F was assumed to be zero because the soil water content at depth was small enough that hydraulic conductivity was negligible throughout the growing season. Values of change in soil water stored in the profile (ΔS) were calculated with the integral calculus method. Having calculated the ΔS for each treatment of the experiment, we determined the ET for the 0–150 cm deep soil control volume (Table 7). Seasonal cotton water use values ranged from 432 to 739 mm, which compared well with values ranging from 594 to 778 mm for a 4-year study of limited and full irrigation of cotton in California (Howell et al., 1987) and with values of approximately 750 mm reported by Howell et al. (2004) for the Texas High Plains.

In 2003 and 2005, both drip irrigation treatments exhibited greater plant height by 1 August than did furrow irrigation; and in 2003 the difference was significant ($P < 0.10$ here and elsewhere in Table 8). Number of bolls by 1 September was significantly larger for treatment 2 (drip irrigation at 70–70–60% of F_C) in 2003 and 2004. There were few significant differences in numbers of nodes, but when they occurred the number of nodes was greater for treatment 2. Despite the almost complete lack of significant differences in 2005, treatment 2 yielded more than did the other treatments.

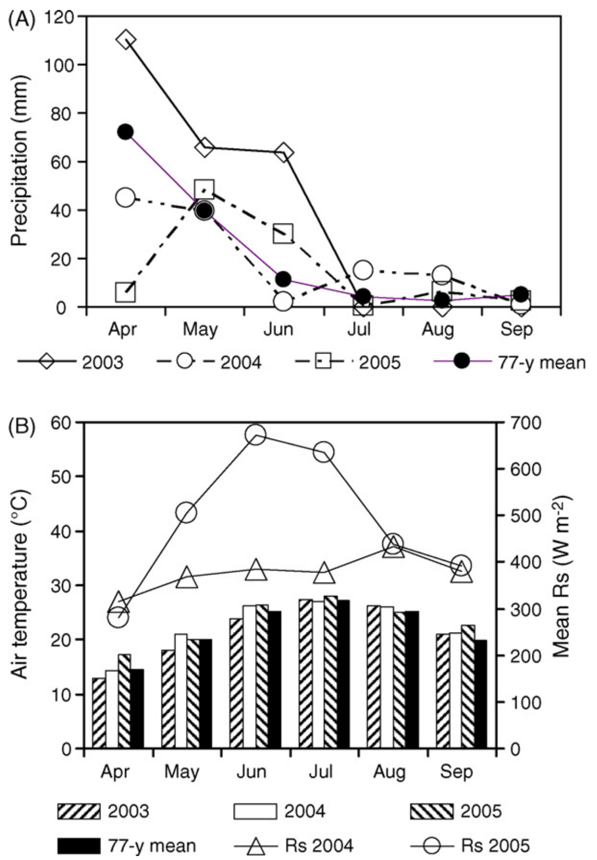

Fig. 1 – Monthly mean meteorological data for the 2003, 2004, and 2005 cotton growing seasons at the Cotton Growing Research Institute, Tashkent, Uzbekistan. (A) Precipitation for the three seasons compared with the 77-year means. (B) Air temperature for the three seasons compared with the 77-year mean. For 2004 and 2005, the solar irradiance (R_S) was available and is shown.

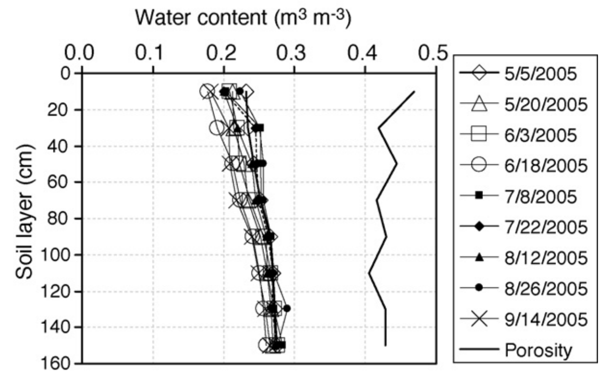

Fig. 2 – Example of soil water profile data. Profile water contents values from 5 May to 14 September 2005 were always well below the saturated water content as indicated by the soil porosity. For clarity, every other reading is omitted.

Seed-lint yields ranged from 3.18 to 4.03 Mg ha^{-1} ($P < 0.05$ in Table 9). Lint yield averaged 35% of seed-lint mass (data not shown), so lint yields were in the range of 1.11–1.41 Mg ha^{-1}, smaller than the range of 1.58–1.93 Mg ha^{-1} reported for lint yields by Howell et al. (1987). Plant population in that study was ~10 plants m^{-2} versus the 9 plants m^{-2} in this study. Other than the smaller plant number, the yield difference is difficult to explain for several reasons—cotton is hand picked in Uzbekistan and is picked more than once (up to four times, twice in this study); there is no appreciable salinity at the Tashkent location, and the environment at Tashkent is generally less stressful than that in the San Joaquin Valley of California. Yield differences thus are probably due to a combination of plant number and varietal differences. The 35% gin turnout is somewhat smaller than the 38% that is typical for U.S. cotton (Lewis, 2000), which points to a varietal difference. However, lint yields were very close to the range of 1.12–1.50 Mg ha^{-1} reported by Howell et al. (2004) for sprinkler-irrigated cotton at Bushland, Texas in the Texas High Plains.

Yield is also influenced by the heat units available in a given climate. Daily growing degree days, calculated as the mean of the daily maximum and minimum air temperatures less a base temperature of 15.6 °C (Peng et al., 1989), summed to 1476 °C days over the 2004 growing season and 1529 °C days in 2005 (summed from planting to first harvest; maximum and minimum daily temperature data were not available for 2003). This is within the upper end of the range of heat units reported by Wanjura et al. (2002) for 12 years of drip irrigated cotton at Lubbock, Texas (190 km south of Bushland); but our heat units were larger than the maximum of 1130 °C days reported by Howell et al. (2004) for 2 years at Bushland. Wanjura et al. (2002) reported lint yields ranging from 1.33 to 1.63 kg m^{-2}, slightly larger than our results at Tashkent. Overall, heat unit accumulation and yield results at Tashkent (latitude of 41°42′N, elevation of 625 m) were reasonably close to those from Lubbock, Texas (latitude of 33°33′N, elevation of 992 m).

Table 7 – Treatment-mean water use (ET, mm) of cotton in 2003, 2004, and 2005 at the UNCGRI Central Research Station, Tashkent, Uzbekistan

Year	Treatment		
	1	2	3
Change in storage ($-\Delta S$, mm)			
2003	−4	−2	3
2004	−40	−19	−36
2005	−32	−27	−43
Irrigation (*I*, mm)			
2003	308	327	515
2004	317	348	595
2005	460	484	592
Precipitation (*P*, mm)			
2003	130	130	130
2004	75	75	75
2005	104	104	104
Crop water use (ET, mm)			
2003	442	459	642
2004	432	442	706
2005	596	615	739

Table 8 – Plant growth development during the cotton vegetation

Treatment number	Treatment (% of F_C)	Irrigation method	Plant height (cm)			Number of sympodial branches		Number of bolls per plant	
			1 June	1 July	1 August	1 July	1 August	1 August	1 September
2003									
1	65–65–60	Drip	8.1 a	32.3 c	61.6 ab	4.4 a	10.6 b	6.4 a	12.4 b
2	70–70–60	Drip	7.9 a	34.6 b	63.1 a	4.1 a	12.5 a	5.5 b	13.9 a
3	70–70–60	Furrow	8.1 a	37.0 a	59.7 b	4.3 a	10.9 b	6.1 ab	11.3 c
2004									
1	65–65–60	Drip	9.0 b	38.5 a	63.1 a	4.5 ba	6.7 a	4.0 a	9.7 b
2	70–70–60	Drip	10.0 a	38.4 a	53.9 b	4.8 a	7.8 a	4.2 a	12.1 a
3	70–70–60	Furrow	8.8 b	28.5 b	54.5 b	3.7 b	7.4 a	2.5 b	8.6 b
2005									
1	65–65–60	Drip	21.0 a	41.7 a	79.5 a	6.7 a	10.7 a	7.6 a	12.3 b
2	70–70–60	Drip	23.6 a	41.6 a	78.2 a	6.9 a	10.4 a	8.9 a	12.8 ba
3	70–70–60	Furrow	23.5 a	43.6 a	77.7 a	7.1 a	11.2 a	9.1 a	14.1 a

Means with the same letter in one column and year are not significantly different (LSD, $P < 0.10$).

The largest yield for drip irrigated treatments in all years was obtained with treatment 2 (70–70–60% of F_C, Table 9). Yield for treatment 2 was significantly greater than that for treatment 3 (70–70–60% of F_C by furrow irrigation) in 2003 and 2004, and it was significantly greater than that for treatment 1 (65–65–60% of F_C by drip irrigation) in 2004 (Table 9). Treatment 1 was considered to represent a deficit irrigation schedule due to its consistently smaller yield. For drip irrigation, additional yield received with treatment 2 (70–70–60% of F_C) in comparison with scheduling of irrigation at 65–65–60% of F_C was from 3 to 7%. Additional yield for drip irrigation compared with furrow irrigation ranged from 7 to

Table 9 – Seed–cotton yield, irrigation, total water use efficiency (WUE) and irrigation water use efficiency (IWUE) of cotton in 2003, 2004, and 2005 at the UNCGRI Central Research Station, Tashkent, Uzbekistan

Treatment number	Treatment (% F_C)	Irrigation method	Irrigation ($m^3\ ha^{-1}$)	Yield ($Mg\ ha^{-1}$)	Irrigation water requirement ($m^3\ Mg^{-1}$)	IWUE ($kg\ m^{-3}$)
2003						
1	65–65–60	Drip	3080	3.36 ba	916	1.09 a
2	70–70–60	Drip	3270	3.59 a	910	1.10 a
3	70–70–60	Furrow	5150	3.18 b	1619	0.62 b
2004						
1	65–65–60	Drip	3170	3.40 b	932	1.07 a
2	70–70–60	Drip	3480	3.90 a	892	1.12 a
3	70–70–60	Furrow	5950	3.28 b	1814	0.55 b
2005						
1	65–65–60	Drip	4600	3.78 a	1216	0.82 a
2	70–70–60	Drip	4840	4.03 a	1200	0.83 a
3	70–70–60	Furrow	5920	3.66 a	1617	0.62 b
Treatment number	Treatment (% F_C)	Irrigation method	ET ($m^3\ ha^{-1}$)	Yield ($Mg\ ha^{-1}$)	Total water requirement ($m^3\ Mg^{-1}$)	WUE ($kg\ m^{-3}$)
2003						
1	65–65–60	Drip	4421	3.36 ba	1107	0.76 a
2	70–70–60	Drip	4588	3.59 a	1089	0.78 a
3	70–70–60	Furrow	6418	3.18 b	1836	0.50 b
2004						
1	65–65–60	Drip	4316	3.40 b	788	0.79 b
2	70–70–60	Drip	4423	3.90 a	960	0.88 a
3	70–70–60	Furrow	7061	3.28 b	1845	0.46 c
2005						
1	65–65–60	Drip	5957	3.78 a	1405	0.63 a
2	70–70–60	Drip	6147	4.03 a	1337	0.66 a
3	70–70–60	Furrow	7385	3.66 a	1708	0.50 b

Means with the same letter in one column and year are not significantly different ($P < 0.05$).

15% using the same irrigation scheduling treatment of 70–70–60% of F_C.

Irrigation WUE was always significantly larger for drip irrigation (0.82–1.12 kg m^{-3}) than for furrow irrigation (0.55–0.62 kg m^{-3}) (Table 9). The same was true for total WUE (range of 0.63–0.88 kg m^{-3} for drip versus 0.46–0.50 kg m^{-3} for furrow). Converted to WUE for lint yield rather than for seed-lint yield, the WUE values ranged from 0.22 to 0.31 kg m^{-3} for drip versus 0.16 to 0.18 kg m^{-3} for furrow. The drip WUE values for lint yield were almost identical to the range of 0.265 ± 0.036 kg m^{-3} reported by Howell et al. (1987) for drip and furrow irrigated cotton, while the furrow WUE values were within the range of 0.15–0.19 kg m^{-3} reported by Howell et al. (2004) for sprinkler-irrigated cotton in the Texas High Plains. Howell et al. (1987) did not find a difference in WUE between drip and furrow application methods. However, their furrow irrigation runs were short (91 m) and the plots had 0.4% slope, making furrow irrigation very efficient.

Some experiments have shown that drip irrigation does not increase yield relative to well-managed surface (e.g., furrow) irrigation (Howell et al., 1987; Bucks et al., 1988). Others have shown that drip irrigation may increase lint yield and WUE by large amounts compared with those from sprinkler or surface irrigation (Smith et al., 1991; Bordovsky, 2001; Janat and Somi, 2002; Kamilov et al., 2003). In our experiment, drip irrigation showed its superiority over conventional furrow irrigation as practiced in Uzbekistan. Although it is often mentioned that drip irrigation is hardly used in Uzbekistan due to its large capital cost, drip irrigation should be further explored as an effective means to control quantity and placement of irrigation water in Uzbekistan, in particular for cotton. This is imperative not only to save water, but also because water pricing is foreseen in the near future. A recent study showed that farmers may only become affected by water pricing when confronted by prices several times larger than the prices currently discussed in Uzbekistan (Bobajanov and Lamers, 2005).

4. Conclusions

Overall, our investigations with cotton conducted in a deep silt loam soil of Tashkent Province, Uzbekistan, showed that the NMM was useful for determining water content dynamics of soil profiles, scheduling irrigation during growing seasons, and obtaining accurate data on water use.

Irrigation WUE for drip irrigation was increased by 71% on average compared with that of furrow irrigation when scheduling was based on the (70–70–60% of F_C) rule for both. The seed–cotton yield under drip irrigation was increased by 14% on average relative to that for furrow irrigated cotton.

Averaged over three seasons, scheduling drip irrigation following the 70–70–60% of F_C treatment resulted in saving 32% of the irrigation water in comparison with furrow irrigated cotton irrigated following the same scheduling rule.

The optimum irrigation scheduling regime (70–70–60% of F_C) should be considered as an improved practice for drip irrigated cotton, which is applicable for irrigated Calcic Xerosols of Uzbekistan. Also, the yield improvement associated with conversion to drip irrigation was substantial; and further economic analysis should be done to establish the economic feasibility of converting large areas of cotton production from furrow to drip irrigation.

Cotton varieties that yield a larger ratio of lint to seed mass should be investigated to improve gin turn out.

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